

Development Of A Full Hybrid Lighting-CPV Prototype And Savings In A Real Case Operation

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Abstract. A full Hybrid lighting-CPV prototype has been assembled. This new concept mixes a classical CPV module with the production of light for illumination without a double conversion (solar energy to electricity and electricity to light) allowing a higher efficiency to the whole system. The present prototype is based on a commercial CPV module that has been adapted in order to be hybrid, adjusting the receivers to pass the fibers into the module, inserting a holder to adjust x,y and z position of the fibers and changing the original parquet of lenses by a bifocal one composed most of the original lenses and the inclusion of other lenses in the position of the corners. Results show that with a minimal loss in the CPV part, a luminous flux is obtained that can be used to illuminate. Adding an additional electrical lamp and a light sensor that enables this lamp when no light from the sun is received, a 38% saving on lighting electricity is expected in Madrid during a year.

INTRODUCTION

A way to improve CPV systems has been the increase of the efficiency, through the use of more efficient photovoltaic cells. However, another option with a more efficient use of the solar resource is presented here. It consists of a hybrid CPV module where a small part of the receiver area is used to inject light in optical guides, additionally to the area that concentrates sunlight to solar cells. The basic improvement lays on that only it is necessary to transport the solar energy and not to convert first to electricity and then again to light, decreasing the total efficiency.

In fact, lighting with sunlight with optical guides is already a commercial technology [1, 2]. It consists of introducing concentrated direct sunlight on optical fibers. However, the tracker, the concentrating optics and so on requires an extremely long pay-back time, when only light is produced. With the Hybrid lighting CPV concept these needs are shared, and at the same time the production of light is achieved at higher efficiency.

Obviously this approach limits the domain where this system can be installed, but at the same time it smoothes the path of building integration CPV.

DESCRIPTION OF THE CONCEPT

As it was presented, an approach to improve the efficiency of CPV systems is to use the sunlight

directly to light a room. That means that a part of the concentrated light that goes to the photovoltaic cell can be directed to a light guide, and then to use it to illuminate.

In Figure 1 it can be checked a possible implementation where there is a parquet of lenses that can concentrate in both optical fibers and photovoltaic cells. Notice that the optical fiber lenses are placed in the corners of the CPV lenses, the less efficient region of a Fresnel lens.

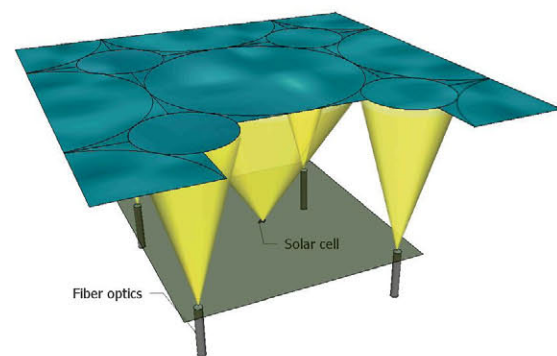


FIGURE 1. Artistic impression of an adaptation of optical fiber in CPV *bifocal* parquet of lenses

The improvement achieved by this approach is shown in Figure 2. On the left side there is a classic multijunction high efficient CPV system that is connected to an LED lamp to obtain 2190 lumens. However, as it can be checked on the right side, if a

part (35%) of the sunlight is oriented to a light guide that transports 65% of the total, it can be obtained the initial 2190 lumens, plus the rest of the 65% of the original electricity.

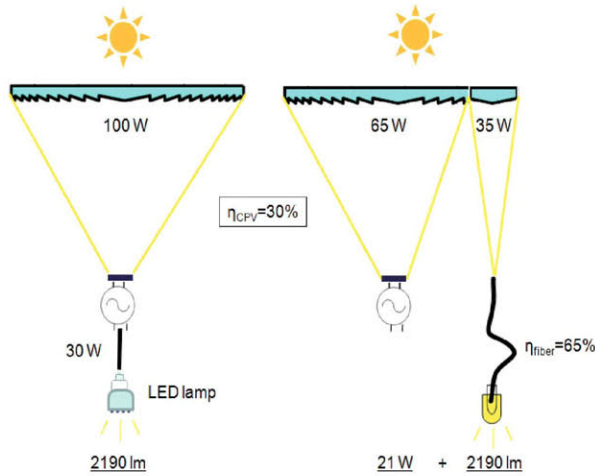


FIGURE 2. Comparative schema: classic CPV and Hybrid Lighting-CPV

PROTOTYPE DESCRIPTION

The previous approach has been implemented adapting a commercial CPV module from Martifer, a module based in Silicon On Glass primary and Secondary Optical Elements on MJ cells.

Two are the main changes to convert the CPV module to a Hybrid one: 1- to change the parquet of lenses to a *bifocal* one, as it was presented above and 2- to adapt the internal structure to host the optical fibers.

Externally original and Hybrid modules looks the same, except the external tubes that carry inside the optical fibers.

Parquet Of Lenses

A new parquet of lenses has been designed from the original one, inserting another set of lenses that inject sunlight to the optical fibers. The CPV lenses has just been reduced on the corners, keeping the original design, $120 \times 120 \text{ mm}^2$ (except 5.3% due to corners) and 200 mm of focal length.

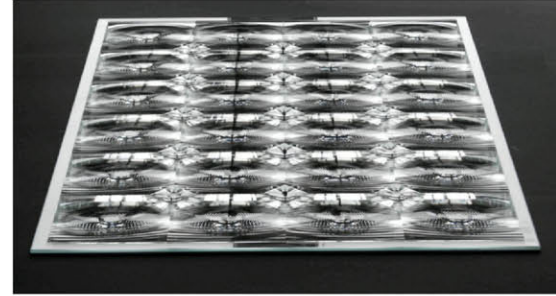


FIGURE 3. *Bifocal* parquet of lenses. Similar to classical CPV parquets, includes another set of lenses in the lenses corners to inject light to optical fibers

The lighting lenses has an area of $35 \times 35 \text{ mm}^2$ and 115 mm, injecting the maximum power that allow the material of the optical fibers (PMMA) and a high *f-number*, as a trade-off between spot size and a reduced cone of light, to avoid the minimum absorption inside the fiber due to reflections [3]. Figure 3 shows a picture of it.

It should be noticed that the original CPV design and the material of optical fibers act as constraints to have a higher percentage of area of parquet dedicated to lighting as is proposed in the description of the concept. However, the proposed prototype is a full suitable one, and validates the concept.

Module Adaptation

A metallic grid has been placed in the middle of the module in order to place the optical fiber in the proper position, as can be checked in Figure 4.



FIGURE 4. Optical fiber holder sited inside the Hybrid module to place fibers in the proper position and focal length

Also the receiver has been open with holes to allow the fibers to pass in, and they are conducted indoor with corrugated tubes to protect them, as shown in Figure 5.



FIGURE 5. Rear view of the Hybrid module, showing the exit of optical fibers from the CPV receiver

Optical fibers are PMMA made with a 3 mm diameter and 17 m long, from solar tracker until the laboratory. Both ends have been polished with sandpaper and polish spray to allow the best optical coupling.

PROTOTYPE RESULTS

Electrical Results

The original CPV module is composed of 24 cells in series. The I_{sc} is 1.5 A and V_{oc} 70.4 V, having a P_{mp} of 84.5 W at Standard Operation Conditions (SOC, $DNI = 900 \text{ W/m}^2$, $T_{amb} = 20 \text{ }^\circ\text{C}$ and spectrum similar to AM1.5D).

These electrical results are similar to those obtained by the original CPV module. The largest change that can be noticed in the CPV part is the reduction of 5.3% of area that is translated in a similar reduction in current.

In Figure 6 it can be noticed this reduction in photocurrent, while the rest of the IV curve remains the same.

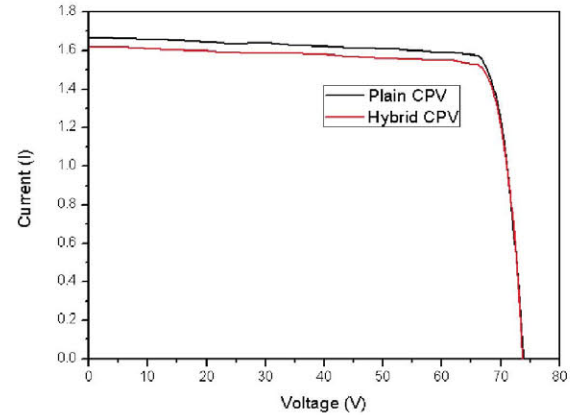


FIGURE 6. IV curve of a original CPV module before and after the use of area as lenses for lighting

The results are from a only CPV module where the area for optical fibers was modified without the change of the parquet of lenses. In this case, the area reduction was slightly inferior, about 3.1%

Lighting Results

At the end of fibers we get 467 lumens, normalized to the same conditions of the electrical part, SOC, about 31 lumens per fiber.

The emittance angle is $\pm 14^\circ$, due to the *f-number* of the injecting lens. However due to the small diameter of fibers, the luminance is about 10^8 cd/m^2 , what overpasses the limit of eye damage (10^6 cd/m^2). To adapt the generated light appropriately to a room, a diffuser is necessary, as shown in Figure 7

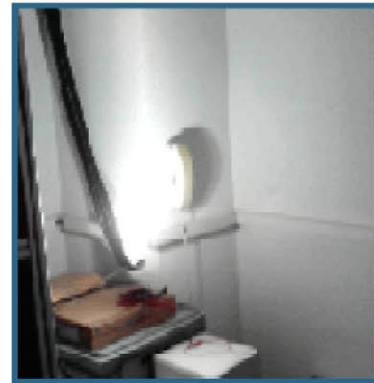


FIGURE 7. End-side of the Hybrid system, where light transported by the optical fibers can be used as a lamp

Another important lighting feature is the tone of white light, measured as Correlated Color Temperature, and indicates the estimated black body temperature that should be considered for the spectrum emitted by the optical fibre. Measures from fibers

show values a little higher than direct sunlight (5784 K). This CCT represents a slightly bluish white light, but still below typical values of other lamps with values over 6000 K, as daylight fluorescent lamps that are widely used in offices and public areas.

Combining Hybrid With An Electrical Lamp

Once the module is placed in a tracker to collect solar radiation, a follow-up about the real electricity saving is currently going on. Electricity saving is estimated with a light sensor and a backup lighting system (composed of a LED lamp and a light sensor) that only works when the level of light is under an established threshold. Additionally the electricity needed to light the back-up lamp on is monitored by an electricity meter. Figure 8 shows the described schema.

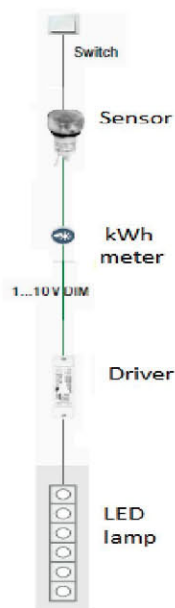


FIGURE 8. Schema of the Hybrid installation including a electrical back-up lamp

First results show that considering Madrid and working time of 12 hours (from 8h to 20h), savings on electricity of lighting achieve 38% extrapolating for an annual period.

CONCLUSIONS

A Hybrid Lighting-CPV module has been assembled and operated adapting a CPV commercial module. This new concept

The parquet of lenses needs to be changed to a *bifocal* one that also injects light into optical fibers. Also the chasis of the module needs to be adapted to allow the optical fibers going out and to hold them in the proper focal distance. Nevertheless this modifications are minimal and the cost of producing the *bifocal* parquet of lenses is the same as a only CPV parquet once the mold is made.

A minimum loss in CPV power (5%) is translated in 38% of savings on electrical light in a year (Madrid) considering that the natural light is used always and the electrical lamp works as a back-up.

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